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A new calibration of the RGB Tip as a Standard Candle

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Abstract. We have obtained an accurate estimate of the absolute I magnitude of the Tip of the Red Giant Branch (M_I^{TRGB}) for the globular cluster ω Centauri, based *(a)* on the largest photometric database ever assembled for a globular, by Pancino et al. (2000), and *(b)* on a direct distance estimate for ω Centauri, recently obtained by Thompson et al.(2001) from a detached eclipsing binary. The derived value $M_I^{TRGB}= -4.04 \pm 0.12$ provides, at present, the most accurate empirical zero-point for the calibration of the $M_I^{TRGB}-$ [Fe/H] relation, at [Fe/H]~ -1.7.

1. Introduction

While the use of the luminosity of the Tip of the Red Giant Branch (TRGB) as a standard candle dates back to 1930 (see Madore & Freedman 1998 and references therein), the development of the method as a safe and viable technique is relatively recent (Lee, Freedman & Madore 1993, hereafter L93). In a few years it has become a widely adopted technique, finding fruitful application also within the *HST Key project on the Extragalactic Distance Scale*. The underlying physical processes are clearly understood and well rooted in the theory of stellar evolution (Madore & Freedman 1998). The method is particularly useful to estimate distances to those stellar systems that do not contain Cepheids, such as early type galaxies, and it can be applied to galaxies as far as ~ 12 Mpc with the current instrumentation. The key observable quantity is the magnitude of the bright end (the tip) of the Red Giant Branch (RGB), that corresponds to a sharp cut-off in the RGB Luminosity Function (LF), measured in the Cousin's I passband.In this passband the magnitude of the tip shows a very weak (if any) dependence on metallicity (Da Costa & Armandroff 1990, hereafter DA90). The feature can be identified by applying the Sobel's filter, an edge-detection algorithm, to the LF of the upper RGB (see Sakai, Madore & Freedman 1996,

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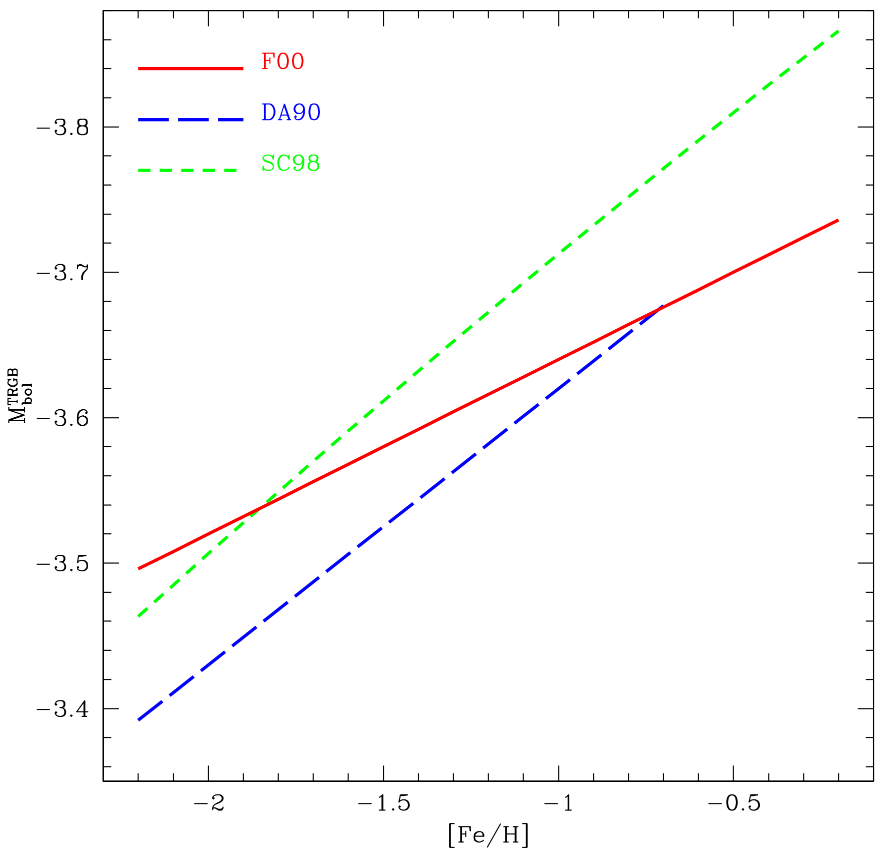

Figure 1. Comparison between different relations between M_{bol}^{TRGB} and [Fe/H], providing the basis for the calibration of the M_I^{TRGB}vs. [Fe/H] relations. The empirical calibrations by DA90 and F00 are compared to the theoretical calibration by SC98.

hereafter S96, for a standard application). The possible biases have been well characterized and quantified by means of numerical simulations by Madore & Freedman (1995; hereafter MF95).

In this context, we are performing an extensive study of the Red Giant population in Galactic Globular Clusters (GGC). In particular, we have derived an accurate calibration of the RGB photometric properties as a function of metallicity, both in the optical and in the IR (Ferraro et al. 1999, 2000). The final aim of this program is to use stellar populations in GGCs as *calibrators* for the TRGB method, taking advantage of the large samples that can be easily assembled with the new generation of array detectors and cameras. As a part of this general project, we present *(i)* a very robust empirical calibration of M_I^{TRGB}at $[Fe/H] \sim -1.7$, derived by applying the *standard analysis* to a very large sample of RGB stars in the globular cluster ω Centauri (NGC 5139), and based on a direct distance estimate recently obtained by Thompson et al. (2001, hereafter T01) for a detached eclipsing binary in this cluster, and *(ii)*

a new *empirical* calibration of the M_I^{TRGB}– $[Fe/H]$ relation based on a large, homogeneous IR database of RGB stars in Galactic Globular Clusters, recently published by Ferraro et al. (2000; hereafter F00).

The results of this analysis are reported in full detail in Bellazzini, Ferraro & Pancino (2001; hereafter BFP01).

2. The M_I^{TRGB}vs [Fe/H] relation

The most widely adopted calibration of the absolute I magnitude of the TRGB is based on small samples of RGB stars observed in a few templates globulars (in the range $-2.2 \leq [Fe/H] \leq -0.7$), and relies on the RR Lyrae distance scale (L93, DA90). Such calibration suffer from two major sources of uncertainty:

- The evolution of stars along the RGB becomes faster as their luminosity increases along the path toward the TRGB. Thus, most of the cluster light has to be observed to correctly sample the fastest evolutionary phases. MF95 stated that acceptable detections of the TRGB can be obtained if more than 50 stars are sampled within 1 mag from the tip and that fine estimates can be obtained only sampling more than 100 stars in that range. The DA90 samples are much poorer than this, therefore their I^{TRGB}estimates may be affected by the systematics associated with small number statistics.

- The RR Lyrae distance scale is quite uncertain. While there is now some agreement on the slope of the $M_V(RRLy) - [Fe/H]$ relation, the actual zero points is still hardly debated (see Cacciari 1999, for a recent review).

Ferraro et al (2000; hereafter F00) have recently presented a similar calibration based on NIR photometry of nine templates globular clusters. With respect to LF93 the calibration of F00 (1) is based on larger samples of RGB stars, (2) it is less affected by uncertainties in the reddening, because of the adopted NIR passbands, and (3) it extends the range of application to $-2.2 \leq [Fe/H] \leq -0.2$. The final calibrating relation for $M_I^{TRGB}$is (see BFP01):

$$M_I^{TRGB} = 0.14[Fe/H]^2 + 0.48[Fe/H] - 3.66 \qquad (1)$$

Eq. (1) represents a substantial improvement with respect to previous work, since it is based on the largest RGB samples in GGCs available in the literature. Note that the F00 survey sampled a significant fraction of the cluster light (up to $\sim 80\%$). However even in this large data-set the number of RGB stars in the upper 1 mag bin from the TRGB is < 50 in all the cases, and the brightest star detection is possibly prone to low number statistics effects. This is due, in most cases, to intrinsic poorness of the cluster population, since the majority of GGCs simply *do not contain a sufficient number of RGB stars* to adequately sample the upper RGB. Thus extensive observations of the most massive GGCs are urged in order to properly calibrate the above relation.

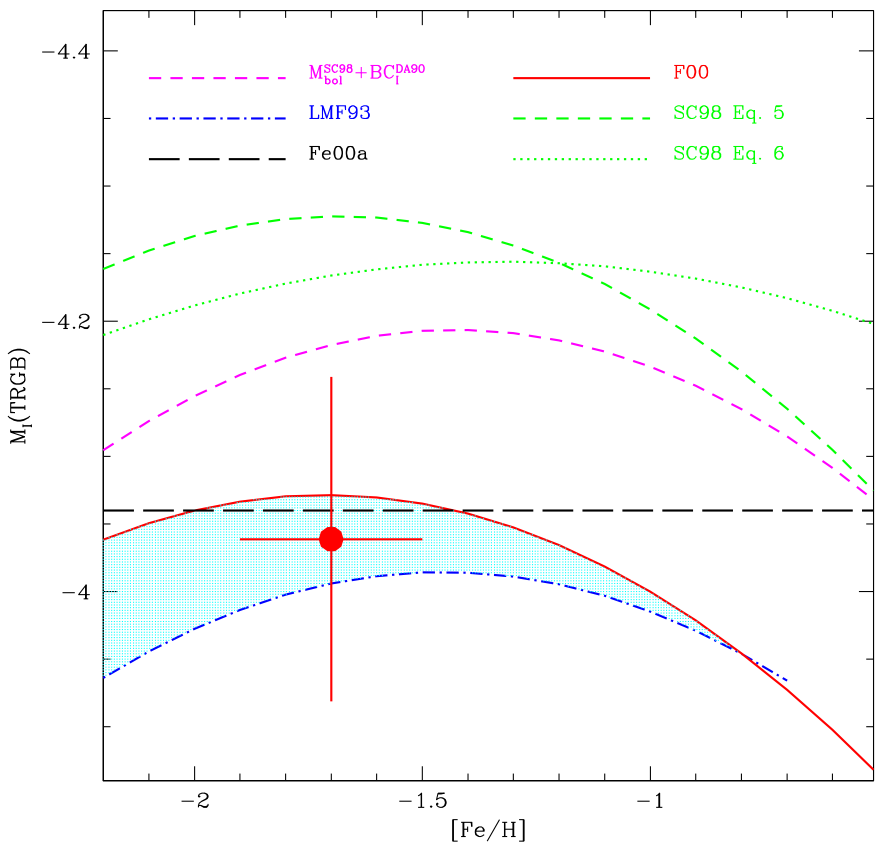

Figure 2. Comparison between the calibration of M_I^{TRGB} obtained for ω Centauri and different M_I^{TRGB} – [Fe/H] relations. The short dashed curve between the SC98 relations and the shaded area (see text) is the calibration obtained by coupling the M_{bol}^{TRGB} vs. [Fe/H] relation by SC98 and the empirical BC_I by DA90.

3. A firm zero point for the TRGB calibration

ω Centauri is a nearby and well studied cluster. It is the most luminous globular cluster in the Milky Way system, therefore even the fastest evolutionary phases are well populated and it is possible to observe a quite large sample of RGB stars, fulfilling the prescriptions of MF95. Here we adopt the huge photometric (B,I) database presented by P00, consisting of more than 220,000 stars observed with the WFI camera at the 2.2 ESO-MPG telescope and extending over a $\sim 34' \times 33'$ field roughly centered on the cluster. The absolute photometric calibration is accurate to within ± 0.02 mag. The observed field extends over ~ 24 core radii, i.e. an area enclosing 90% of the cluster light. Thus, virtually *all the bright stars of ω Centauri are included in the adopted database.* Considering that ω Centauri is the most luminous globular cluster of the whole Galaxy, this

photometric database is the largest sample that can be obtained in the Galactic globular cluster system.

Moreover, ω Centauri was the first globular in which a detached eclipsing binary system, *OGLEGC17*, was discovered (Kaluzny et al. 1996). This enabled T01 to obtain a direct distance estimate, independent of any other distance scale. This method is basically *geometrical*, since the distance is obtained by comparison between the linear and angular size of the binary members (see Kruszewski and Semeniuk 1999, for a recent review and references). The final distance obtained by T01 is $d = 5385 \pm 300$ pc, which corresponds to $(m-M)_0 = 13.65 \pm 0.11$, if we assume their adopted extinction value, $E(B-V) = 0.13 \pm 0.02$. Their result is in good agreement with previous estimates. According to T01, the error bar on the distance modulus can be significantly reduced as soon as better light and velocity curves will be obtained for *OGLEGC17*. Thus, a significant improvement of the quoted measure of the distance modulus has to be expected in the near future.

The huge P00 sample allowed us to succesfully perform *the first measure of the TRGB in a Globular Cluster using the Standard Technique*, i.e. by detecting the cut-off of the RGB luminosity function with an edge-detector filter (see BFP01 and references therein). Coupling our optimal measure of the TRGB with the distance and reddening presented by T01 we obtained:

$$M_I^{TRGB} = -4.04 \pm 0.12 \tag{2}$$

where *all* the sources of uncertainty have been taken into account. The main contributor to the error budget remains the estimate of the distance modulus. Even at the present level of accuracy, the M_I^{TRGB}measure derived here is the less uncertain calibrating point for the $M_I^{TRGB}-$ [Fe/H] relation.

4. Comparisons with other calibrations

In Figure 2 our estimate of M_I^{TRGB} in ω Centauri is reported as a *big black dot* in the M_I^{TRGB}vs. [Fe/H] plane. The horizontal error bar represents the range in metallicity covered by the dominant population of the cluster (see BFP01).

The *heavy solid curve* is the new calibration based on the large IR database by F00, while the L93 calibration is plotted as a *dotted-dashed curve.* The horizontal *long dashed line* represents the recent result by Ferrarese et al. (2000 hereafter Fe00a) who calibrated the TRGB as a secondary indicator by using Cepheid distances in a small set of nearby galaxies where both Cepheids and the TRGB have been detected. They found $M_I^{TRGB} = -4.06 \pm 0.07$ (random) ± 0.13 (systematic), in very good agreement with our estimate, despite their larger uncertainty. We plotted also the region delimited by the two empirical calibrations as a *shaded area*, in order to point out the region of the plane where most of the empirical estimates lie.

Salaris & Cassisi (1998; hereafter SC98) provided a theoretical relation of M_I^{TRGB} as a function of metallicity (see BFP01). Using two different bolometric corrections, SC98 derived two slightly different relations (their eq. 5 and 6), which are reported in Fig. 2 as a *short dashed curve* and as a *dotted curve*, respectively.

As can be seen from Fig. 2, the *theoretical* calibrations are systematically (~ 0.2 mag) brighter than *empirical* ones, as already noted by SC98 and Fe00a. The strong constraint provided by the TRGB luminosity in ω Centauri seems to favor the empirical calibrations.

It is interesting to note that if the theoretical M_{bol}^{TRGB} vs. [Fe/H] relation by SC98 is coupled with the empirical BC_I by DA90 the difference with the purely empirical calibrations (shaded area) is reduced. This fact suggests that the uncertainties in the bolometric corrections may significantly contribute to the observed mismatch between the theoretical predictions and the ω Centauri observed point, which is *fully independent* from BC_I.

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